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Agricultural Memorandum No 332

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Climatically Suited Areas for Grain Maize in UK

This memorandum gives some possible methods for determining the area in UK suited to growing grain maize. Two approaches are discussed: classical growth analysis and accumulated evapotranspiration.

Classical Growth Analysis

In this method the growth rate $\frac{dG}{dt}$ (accumulation of dry matter per unit time) is assumed to depend upon the growth already made G, radiation intensity and the fertilizer and moisture status of the soil. When it is assumed that soil status and radiation are optimum for growth, then the growth rate is assumed to depend upon temperature and the growth already made.

For maize the growth rate is taken equal to zero for temperatures below $10^{\circ}C$ and linear above, ie

$$\frac{dG}{dt} = G \cdot A\,(T-10)$$

A = constant, T = temperature in $^{\circ}C$.

Hence,

$$\log G = A \int (T-10)\, dt \qquad \ldots\ldots\ldots (1)$$

On this model then, the log (growth) made during a time interval is proportional to accumulated temperature above $10^{\circ}C$.

However, actual growth - temperature curves for maize seedlings show that the growth rate is a maximum at $30^{\circ}C$ with a parabolic law giving a good fit:

$$\frac{1}{G}\frac{dG}{dt} = A\,(T-10)^2 + B\,(T-10) + C$$

A, B, C are constants.

$$\text{or} \quad \log G = A\int (T-10)^2\, dt + B\int (T-10)\, dt + \int C\, dt.$$

For maize C = 0, B = -40A (A negative).

$$\therefore \log G = A \int (t-10)^2\, dt - 40A \int (T-10)\, dt \qquad \ldots\ldots\ldots (2)$$

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The $(T-10)^2$ term is only important for temperatures higher than about 14°C. This seems to be the basis of a system for predicting maize growth proposed by Brown, 1969. He calculates what he calls 'Corn Heat Units' (Y), where for one day:

$$Y = 1.85\ (T\ max-50) - 0.026\ (T\ max-50)^2.$$

T max = daily maximum temperature °F.

Nocturnal temperatures are treated differently. An attempt to obtain Brown's formula is made using a sinusoidal temperature variation:

$$T = \frac{(T\ max - T\ min)}{2} \sin \omega t.$$

T min = daily minimum temperature.

If this is substituted in equation (2), and by assuming $(T\ min-10)^2 \ll (T\ max-10)^2$, or $(T\ min-10) \ll (T\ max-10)$, then

$$\log G = \frac{A}{4}(T\ max-10)^2 \int \sin^2 \omega t.dt - \frac{A}{2}(T\ max-10)(T\ min-10) \int \sin^2 \omega t.dt$$
$$- (40A + 20)(T\ max -10) \int \sin \omega t.dt - 100 \int .dt.$$

Which is of similar form to Brown's formula provided the second term on R.H.S. can be ignored, ie (T min - 10) small.

The assumptions made are equivalent to (1) high daily maximum temperature, (2) daily minimum temperature near 10°C. In Canada where this method is used, these conditions are fairly well satisfied, but in UK maximum temperatures are not usually high enough, so there is some doubt about its application here.

Criticisms of these approaches:

1. Variations of the constants A, B etc in the equations with age of the plant (Milthorpe, 1965): could allow for this by using different constants at different times.

2. No account of night temperature effect since high night temperatures imply greater losses by respiration.

3. No account of plant competition and self-shading of leaves.

4. The assumption of an optimum light intensity is not true for maize as photosynthesis continues to increase with increasing light intensity.

The Use of Accumulated Temperatures (Linear model)

Despite its limitations accumulated temperature can be used as a first approximation to growth provided their limitations are recognized. Climatological estimates can be made quite easily and it has been used to represent the growth of many plants including maize. Maize trials have been conducted at Oxford during the past ten years and yield data obtained. The growers there considered the crop to have failed in some years which allows an estimate to be made of the minimum accumulated temperature for maturity. Supposing that a failure of 1 year in 10 is acceptable to the farmer, then by assuming a normal year-to-year

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distribution of accumulated temperature an estimate of the mean accumulated temperature required to give the accepted failure rate can be found. A brief examination of the Oxford data suggests that 640 - 645 °C days (May-October) would be the minimum for a successful crop (40% m.c.). Summarising Soviet experience Chirkov (1965) suggests that for 11-leaf-maize 628 ± 50 °C days are required from sowing to milky ripe (~ 50% m.c.) and 713 ± 86 °C days for sowing to waxy ripe (~ 25-30% m.c.). Interpolation gives 662 ± 60 °C days for 40% m.c. Thus the Oxford figures are within the range expected from the Russian work. The standard deviation of accumulated temperature in SE England is about 80 °C days and so a mean accumulated temperature of 762 ± 60 °C days would then be required for a failure of 1 year in 10. The large radius of uncertainty associated with the figures are a sign that the approach using linear accumulated temperatures is not very satisfactory. Similar figures given by Chirkov for 14-leaf varieties are 734 °C days (milky ripe) and 851 °C (wax ripe). Clearly very early varieties must be used in Britain if any success is to be achieved at all (see table below).

Monthly mean accumulated temperatures for French and British stations are shown. The French temperatures (measured at 2m) have been corrected to be comparable with British temperatures by using analytical forms of temperature profiles and climatological profile data. For most months corrections are small. A method has been used (Thom, 1954, Shellard, 1959) which estimates accumulated temperature using monthly mean temperature and standard deviation of monthly mean temperature. Values are likely to be 5-10% low in May and October, but almost correct from June to September: between 10 and 15 °C days could be added to the seasonal total shown there. The French stations represent conditions at the northern limit of maize growing in France. Exposure details for the French sites are not known, Rouen in particular could be in an urban area with a consequent increase in accumulated temperature above those in the surrounding rural areas.

Accumulated Temperature above 10°C (°C days). 1950/1969 data

N. FRANCE	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	SEASON
ABBEVILLE	84	152	207	206	149	65	863
LILLE	84	154	210	210	144	56	858
ROUEN	97	168	226	215	156	61	923
ENGLAND							
EAST MALLING	63	140	198	186	123	57	767
WYE	64	138	194	185	131	59	771
WOBURN	58	127	179	170	108	51	693
PORTON	52	125	175	165	108	48	673
ROTHAMSTED	60	126	177	169	111	45	688
WRITTLE	59	139	196	185	126	48	753
EXETER	61	143	193	182	127	63	769
ROSS ON WYE	67	144	190	180	115	49	745
SWANAGE	57	137	194	194	140	76	798

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From the above criteria, Woburn, Porton and Rothamsted would not be recommended, while Ross and Writtle are borderline. This is based on maturity as judged by the moisture content of the grain, yield has not been considered and different criteria will probably have to be developed to take this into account.

Accumulated Evapotranspiration

Apart from temperature, maize growth is adversely affected by dry soil particularly during July when most vegetative growth occurs. Values of soil moisture deficits would be useful here, obtained from rainfall and potential transpiration. Potential transpiration should also be an indicator of growth since:

1. Gross photosynthesis depends upon the amount of incident radiation.

2. Ambient temperature is highly correlated with radiation.

3. A strong transpiration stream inside the plant improves the distribution of manufactured plant materials and uptake of substances through the roots.

A more recent version of Penman's formula may be used (Van Bavel, 1966):

$$LE_o = \frac{\frac{\Delta}{\gamma} H + LB_v \, da}{\frac{\Delta}{\gamma} + 1} \qquad \ldots\ldots (3)$$

where

E_o = potential transpiration, da = saturation vapour deficit of the air.
B_v^o = turbulent transfer coefficient.

$$LB_v = \frac{\rho C_p \, k^2 \, Ua}{\left[\ln z_a/z_o\right]^2} \qquad \ldots\ldots (4)$$

ρ = air density, k = 0.4, U_a = mean wind speed at height z_a, z_o = roughness length of the crop. This expression ((4)) for the turbulent transfer of water vapour is useful since it allows for the large roughness change of maize as growth occurs. A change in z_o from 5 cm to 20 cm increases the aerodynamic term by a factor of 2.5, so its inclusion seems worthwhile.

Estimates of E_o can be obtained from the formula and accumulated. Soil moisture deficit may also be found and E_o varied with deficit in an as yet unknown manner. The simplest would be to assume E_o = 0 above some value of moisture deficit with the full value below this limit.

Radiation (H) is measured on site at Oxford, but temperature, rainfall, wind speed and vapour pressure would have to be obtained from nearby stations. This approach would allow a critical value to be determined and an analysis similar to that for accumulated temperature could be used.

Any comments or suggestions on this paper should be sent to the author.

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